Mars Atmosphere and Regolith COllector/PrOcessor for Lander Ops (MARCO POLO) Atmospheric Processing Module (MARCO POLO APM)

Completed Technology Project (2013 - 2014)

Project Introduction

The multi-NASA center **M**ars **A**tmosphere and **R**egolith **CO**llector/**P**r**O**cessor for **L**ander **O**perations (MARCO POLO) project was established to build and demonstrate a methane/oxygen propellant production system in a Mars analog environment. The MARCO POLO project will provide a demonstration platform for all aspects of Martian soil and atmospheric processing, beginning with the extraction of water from Martian soil, which would then be electrolyzed into hydrogen (H_2) and oxygen (O_2), and the capture of carbon dioxide (CO_2) from the Martian atmosphere to produce methane (CH_4) using H_2 from the water. The lander is designed in a modular fashion with an Atmospheric Processing Module (APM), Soil Processing Module, Water Cleanup Module, Water Processing Module, and Power Production Module. Work at the Kennedy Space Center (KSC) has focused on the Atmospheric Processing Module (APM). The purpose of the APM is to freeze CO_2 from a simulated Martian atmosphere at Martian pressures (~7 mbar) by using dual cryocoolers. The resulting pressurized CO_2 and H_2 are fed to a Sabatier reactor to make CH_4 and water vapor. The CO_2 freezer subsystem has a collection/supply design requirement of 88 g CO_2/hr., and the Sabatier subsystem has a design requirement to produce 31.7 g/hr. CH_4 fuel and 71.3 g/hr. H_2O, which would also be electrolyzed to H_2 and O_2.

The atmosphere of Mars consists of 95.32% CO_2, 2.7% nitrogen, 1.6% argon, and trace amounts of water, carbon monoxide, and several other gases. At 7 mbar, the average pressure on the Martian surface, the freezing point of CO_2 is 150 K (−123^{o}C), which makes it necessary to use a cryocooler as the condensation method. Dual cryocoolers are needed to operate in tandem (one collecting CO_2 while the other is supplying the Sabatier reactor). The Sunpower Cryotel Model GT Stirling cycle cryocooler has the proper cooling capacity, low mass and power, and space flight heritage. Lab testing of three copper cryocooler cold head designs to collect the CO_2 show that only the "Ferris Wheel" design met the APM requirements.

The full APM was designed and constructed during a series of projects at KSC. The current APM CO_2 Freezer consists of two cryocoolers and freezing chambers, a chiller to remove heat from the cryocoolers, a vacuum pump to produce Mars pressures in the chambers, two CO_2.storage tanks, a mass flow controller for simulated Mars atmosphere, and various valves to control gas flow and cooling water flow. Multiple optimization tests at varying flow rates showed that the CO_2 Freezer subsystem captures an average of 99 g CO_2/hr. in 1.4 hr. at a feed rate of 1.2 SLPM of Mars gas simulant, well above the required rate of 88 g/hr. The CO_2 capture fraction averaged 79% while the CO_2 sublimation rate averaged 95 g/hr. As the CO_2 sublimes, it is pumped into the storage tanks at the top of Figure 3.

Photo of the MARCO POLO Atmospheric Processing Module CO2 Freezer Subsystem. The two cryocoolers and freezing chambers are at the lower left. The CO2 storage tanks are at the top.

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To improve the CO_2 conversion efficiency of the Sabatier subsystem and to recover unreacted H_2, a recycling process was added. After the water product is condensed a membrane module separates the CH_4 product from residual CO_2 and H_2, then a compressor recycles the CO_2 and H_2 back through the Sabatier reactor. Testing of the new Sabatier reactor without recycling has been promising, with 97% conversion of the CO_2 without the overheating experienced with a reactor supplied by JSC. Testing of the recycling system is currently underway with the membrane module producing pure CH_4, but without recycling the CO_2 and H_2 yet. Integration and testing of the Sabatier subsystem and the CO_2 Freezer is planned in the near future.

Anticipated Benefits

The APM provides a technology demonstration of one part of a Mars Propellant Production System capable of producing 0.44 kg of methane and 1.77 kg of oxygen per 14 hr. day, which would be sufficient for a small Mars Sample Return mission. MARCO POLO has been proposed as the starting point for the new Advanced Exploration Systems (AES) ISRU project for a long-term ground demonstration of a Mars ISRU system to produce oxygen at 0.200 kg/hr. or more. The ground prototype could lead to an ISRU system on the proposed 2024/2026 Mars Surface Pathfinder that would demonstrate key technologies for crewed missions.

SpaceX has declared its intentions to send people to Mars. The MARCO POLO APM is a key technology for the production of rocket propellant and life support oxygen that would support these ambitions. SpaceX has already expressed an interest in our work.

Carbon dioxide capture and sequestration is under investigation by the Department of Energy. Cryogenic capture of CO_2 is being developed. The MARCO APM project has already improved the CO_2 collection cold head design over the NASA state of the art. This improvement and potential insights into conversion of CO_2 into useful products such as methane could be useful to the DO2 as well.

Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Kennedy Space Center (KSC)

Responsible Program:

Center Independent Research & Development: KSC IRAD

Project Management

Program Manager:

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Project Manager:

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Principal Investigator:

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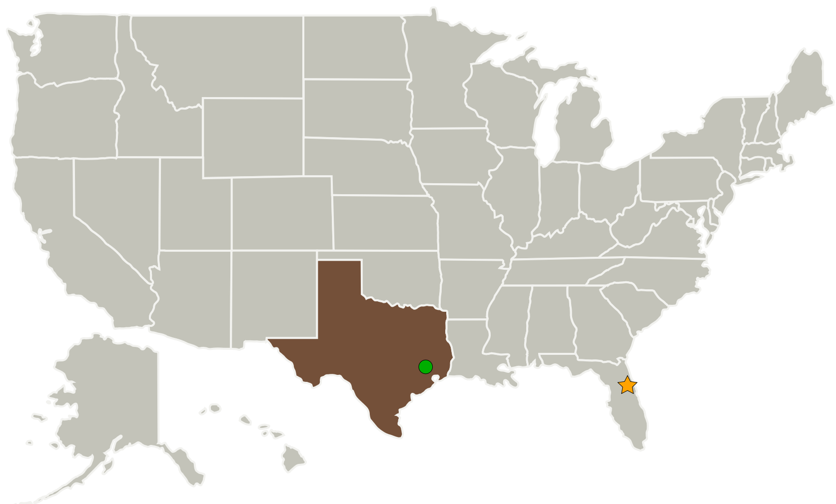
Primary U.S. Work Locations and Key Partners

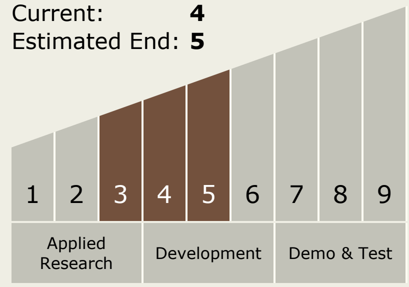


Organizations Performing Work	Role	Type	Location
Kennedy Space Center(KSC)	Lead Organization	NASA Center	Kennedy Space Center, Florida
Johnson Space Center(JSC)	Supporting Organization	NASA Center	Houston, Texas

Primary U.S. Work Locations
Texas

Technology Maturity (TRL)

Start: **3**
Current: **4**
Estimated End: **5**

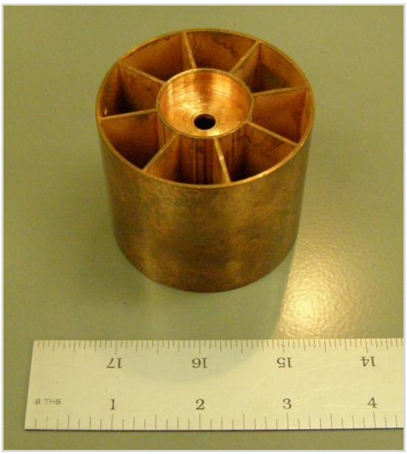


Technology Areas

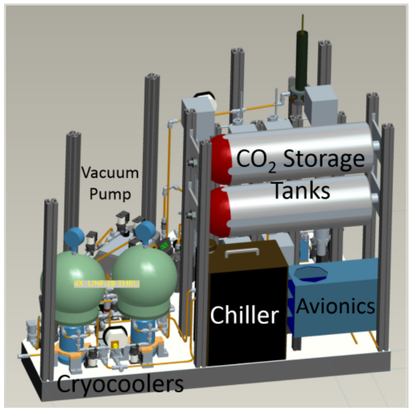
Primary:

- TX07 Exploration Destination Systems
  └ TX07.1 In-Situ Resource Utilization
    └ TX07.1.3 Resource Processing for Production of Mission Consumables

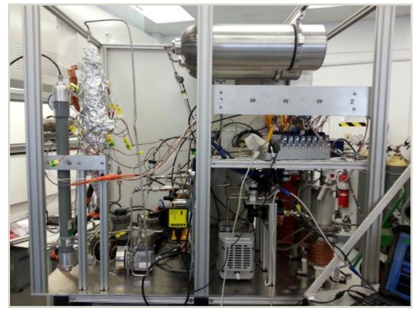
Images



"Ferris Wheel" Cold Head
Photo of the copper "Ferris Wheel" cold head used to collect frozen carbon dioxide.
(https://techport.nasa.gov/image/16068)

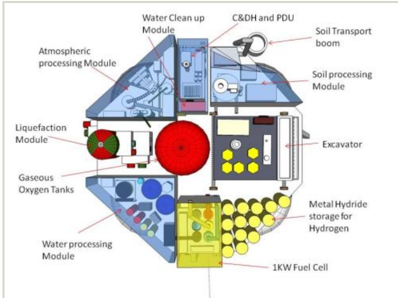


3D Drawing of the Atmospheric Processing Module
3D model of the initial design of the Atmospheric Processing Module.
(https://techport.nasa.gov/image/16069)

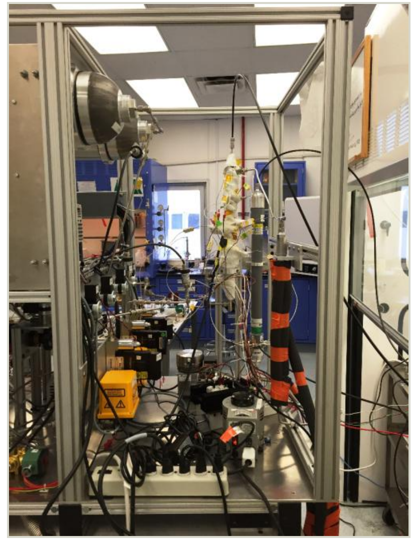


Atmospheric Processing Module
Photo of the Atmospheric Processing Module. The CO2 Freezer is on the right. The Sabatier Subsystem is on the left.
(https://techport.nasa.gov/image/16071)

CO2 Freezer Subsystem
Photo of the MARCO POLO Atmospheric Processing Module CO2 Freezer Subsystem. The two cryocoolers and freezing chambers are at the lower left. The CO2 storage tanks are at the top.
(https://techport.nasa.gov/image/16066)



MARCO POLO System Configuration
Conceptual top-down drawing of the MARCO POLO modules on the lander.
(https://techport.nasa.gov/image/16072)



Sabatier Subsystem
Photo of the Sabatier subsystem while still under development. Near the center is the Sabatier reactor wrapped with white insulation. The membrane module is the gray tube to its right. The condenser is wrapped in black insulation with orange tape.
(https://techport.nasa.gov/image/16067)

Stories

Atmospheric Processing Module for Mars Propellant Production
(https://techport.nasa.gov/file/21078)

KSC Success Story - Mars Atmospheric Processing Module
(https://techport.nasa.gov/file/32705)

Links

KSC-13844
(no url provided)

Prototype Development of an Integrated Mars Atmosphere and Soil-Processing System
(http://ascelibrary.org/doi/full/10.1061/%28ASCE%29AS.1943-5525.0000214)